Vol. XL. DECEMBER, 1898.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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TRANSACTIONS.

No. 837.

MARINE WOOD-BORERS.

By Charles H. Snow, M. Am. Soc. C. E.

Presented at the Annual Convention, July, 1898.

WITH DISCUSSION.

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fined to direct cost. It is said that their presence in abnormal quantities has affected the prosperity of cities. The weakening of the pile foundations and other woodwork of the dikes of Holland once threatened the very safety of that country.

The Teredo Navalis has been observed in Europe for nearly two centuries. The Dutch, from necessity, excelled in the early study of its habits, and the reputation thus established has continued to the present time. Much attention has been devoted to this and other forms of marine wood-borers by American naturalists, among whom the names of A. E. Verrill, of Yale University; S. I. Smith, of the National Fish Commission; W. H. Dall, of the Smithsonian Institution, and lately C. O. Siegerfoos, of the Johns Hopkins Department of Biology, should be mentioned.

The Teredo.

The teredo is a very ancient form of life, fossil remains having been found both in England and America. It was known to the Ancients, and is mentioned in the writings of Pliny and of Ovid. It was observed in modern times about the year 1730, when, as has been stated, it threatened the woodwork of the dikes of Holland.

The Teredo Navalis is often referred to as the Ship Worm, although it is a mollusk. The name is convenient, because the navalis and other teredos resemble worms in appearance, but if it is to be used it should include all forms of the teredo, and not be confined to the species navalis, in which case the names Teredo and Ship Worm rather than the names Teredo Navalis and Ship Worm would be synonymous.

Seven species of the teredo have been identified as existing in the United States. They are the Teredo Navalis (Linn.), the Teredo Norvegica (Spengler), the Teredo Dilatata (Simpson), the Teredo Megotara (Hanley), the Teredo Thompsono (Tryon), the Xylophaga Dorsalis (Forbes and Hanley), and the Xylotrya Fimbriata (Jeffreys). These varieties are similar in their principal characteristics. A description of the teredo may profitably be preceded by a mention of two of the more familiar forms of life which resemble it.

The long or soft shell clam (Myra), is familiar to all. The prominent characteristic is a long worm-like neck, which is out of all proportion to the shell which covers the softer parts. This long neck

contains two tubes or syphons, through one of which the animal receives its sustenance, the other being used to expel the water from which the microscopic life has been withdrawn.

Another form of the same worm-like structure is the razor clam (Solenidæ), whose shape is more nearly conformed to by the covering shell. It possesses a powerful club-shaped foot or sucker, which is used as an auger to penetrate the sand in which it resides. The special features to which attention is called are the long worm-like syphon structure in both the long and razor clam, and the foot or sucker of the latter. A general idea of the teredo can be gained by imagining a soft clam with an unusually long neck and a very small shell, or a razor clam with its shell cut away so as to expose nearly all of its length. The long clam, the razor clam and the teredo are all true mollusks, and only resemble worms in that parts of their bodies are long and round. The shell of the adult teredo covers but a small proportion of its slender worm-like body.

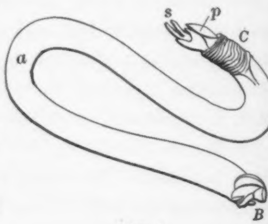
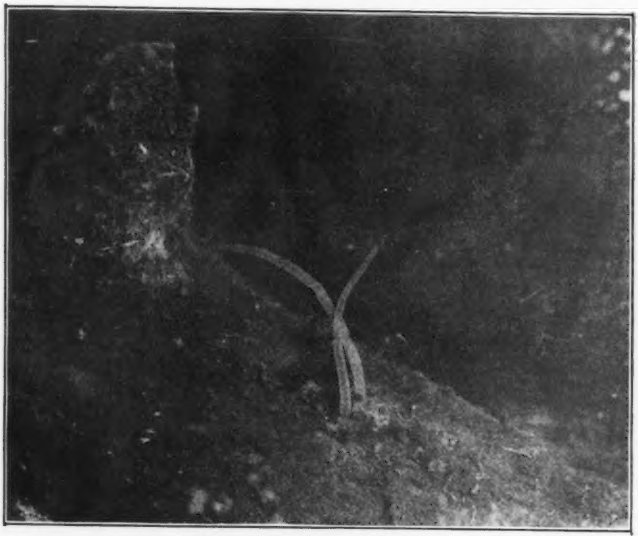


FIG. 1.

The body of the teredo (Fig. 1), which in substance resembles that of the oyster, is long, slender, smooth, soft and gray, tapering somewhat toward the outer or posterior end *s*, where it is marked by a wrinkled collar, shown at *C*. This is the end of the animal which is nearest to the entrance of the burrow. Although the collar attaches the animal to the sides of the boring which it has formed, yet the teredo is free to move to either side of it. The two little horns shown at *s* are the extremities of the tubes or syphons which have been described in connection with the long and razor clams. These little tubes may be extended out through the opening in the wood. They are the portions of the animal which are first noticed by the observer (Plate XIII).

The two little shelly plates, *p*, at the base of the syphon prolongations, are called pallets. They are slightly curved at the top so that they can enfold the syphons. When the syphons are withdrawn into the burrow, the pallets are contracted over them so as to protect these soft tubes from the enemy. The pallet shells are frequently confused with the boring shells, which are at the other end of the body.

PLATE XIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XL, No. 837.
SNOW ON MARINE WOOD-BORERS.



TEREDO AT WORK.—LIFE SIZE.

The principal or boring shells *B*, Fig. 2, which are open both at the top and bottom, are small, and very beautifully formed. The opening at the top permits the emergence of the body, and the foot or sucker *f* passes through the opening at the bottom. A calcareous substance is invariably deposited by the teredo upon the newly cut surface of the wooden tunnel, forming an enameled lining through which the animal can glide backward or forward as it contracts and expands. This shell tube is a separate shell structure, distinct from the pallets and from the boring shell.

It will be seen that the distinctive features of the teredo are the body, the collar, the syphons, the pallets, the boring shell, the foot and the lining shell. These several members and their processes will be considered separately.

The Body.—The body of the teredo resembles that of a long worm, without the articulations. In the young animal it is so transparent that some of the interior organs, such as the heart and the ovary, may be observed through it. The heart consists of two auricles and a ventricle. The pulsations, which may be readily counted, are irregular, the rate being about four or five per minute. The blood is a transparent, colorless fluid. Many of the important organs, as the mouth, the palpi, the liver and the foot, are enclosed in the boring shell at the further extremity of the animal. The gills are located for the most part at the outside of the shell, and are very interesting. They are long and narrow, usually reddish brown in color, and perform the important office of sheltering the eggs and embryo. The nervous system is well developed, and consists of filaments and ganglions connecting the mouth, the branchiæ, the foot, the collar and the syphons. The stomach is not distinguished by any peculiarity, but there is a well-developed intestine. The great length of the body is due to the elongation of the syphons or breathing tubes.*

The Collar.—The collar C, Fig. 1, is a muscular, wrinkled membrane which extends entirely around the posterior portion of the animal, and forms a connection between the teredo and the shelly lining of its tunnel. This is the only place at which the teredo is not free and separated from its surroundings. The collar fills the place between the teredo and the circumference of its tunnel. Water cannot pass through the orifice of the tunnel, save as it is controlled by the

*Johns Hopkins Circular, 1896.

syphons. The collar contains several well-defined muscles, and these act upon the pallets which are pulled down over the syphons in such a manner as to close the entrance to the tube when the extremities of the syphons are drawn into the burrow.

The Syphons.—The syphons are the two principal organs, and extend throughout the greater length of the body. One of these tubes conveys the oxygen, water and infusorial food to the vital processes of the animal; the other conveys the exhausted water, the excretions, the débris from the excavation and the eggs to the free water without. The outer structures of the syphons are united while they remain in the body, but signs of divergence are seen as they emerge from between the pallets. They continue united for a little and are then separated into two distinct tubes, as indicated in Plate XIII. These divergent extremities pass backward and forward through the orifice in the wood. They constitute the only part of the animal which can be seen from the outside of the wood. The extremities often stretch for some distance out through the minute opening to the cell, and are sometimes mistaken for the entire animal.

The extremities, which usually appear to be about equal in length as seen from the exterior of the wood, are yellowish or white in tint, but are sometimes speckled with reddish brown. The longer or incurrent extremity can be pushed out to a distance of 2 ins. or more, while the outcurrent throat remains at about half that distance.

The teredo is able to expand or contract these extremities at will, and when the conditions are favorable, they are extended through the orifice to their full length, and remain stationary or wave slowly backward and forward. The motion is sometimes confined to the extreme ends, while the greater portion of the extended extremity remains stationary. When the animal is alarmed, the syphons are withdrawn and pass down between the pallets into the tunnel; the pallets close over them and protect them from harm. The syphons are erected by means of a current of blood sent into them from the vessels within. When the water is warm, the animal is active and the syphons are extended out full length. They are withdrawn when the water becomes cold, and the teredo is entirely hidden. Plate XIII shows the syphons fully extended as they appeared after several consecutive days of warm weather. The extremities of the syphons must always be kept at the orifice of the wood. As the animal grows, the muscular

PLATE XIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XL, No. 837.
SNOW ON MARINE WOOD-BORERS.

FIG. 1.
LINING SHELL, KUPLIUS GIGANTEA, 41 INS. FROM ENTRANCE.

FIG. 3.—BARNACLE.

FIG. 2.
ENTRANCE, KUPLIUS GIGANTEA, SHOWING DIVISIONS FOR SYPHONS.

FIG. 5.
PALLETS.

FIG. 4.
YOUNG TEREDO.

ALL LIFE SIZE.

collar and the pallets recede from the entrance, so as to permit the extremities of the syphons to remain there.

The Pallets.—The two shelly plates near the orifice are called pallets (Fig. 5, Plate XIV). They are broad and flattened at the top and concentrated at the base. These long slender basal columns are connected with the muscles of the collar so that the pallets may be relaxed or contracted at will. They relax when the syphon extremities pass out between the crescents or horns, which will be seen at the top of the shells, and contract when the syphons are withdrawn. The pallets are then folded over so as to serve as an operculum to protect the soft tubes from enemies. The Xylotrya Fimbriata differs from the ordinary variety in that its pallets are long and oar-shaped. The stalk is slender, the blade is flattened on the inside and is convex externally. It consists of ten or twelve funnel-shaped segments set into one another, and having their margins projecting at the sides, so that the edges of the blade appear serrated.

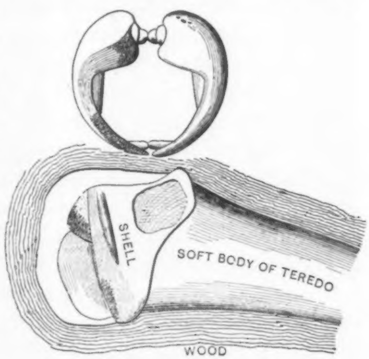


Fig. 2.

The Boring Shell.—The boring shell, which is nearly as long as it is broad, presents an irregularly triangular appearance when observed from the side. It may be best seen in Figs. 1 and 2. The two halves close tightly at the hinge and at the side opposite the hinge; the open space at the top being toward the main bulk of the animal, and the opening toward the extremity of the tunnel permitting the emergence of the foot or sucker. The shells of young animals are larger in proportion than those of old animals, as shown in Fig. 4, Plate XIV. When the animal is very young, it is for a short time entirely enclosed in the shell.

The Foot.—The foot, which in form resembles a pestle, is a short, stout, muscular organ, broadly truncated or rounded at the end, and so arranged that it can exert a powerful suction upon anything to which it is attached. This cupping action assists the shell in excavating to an extent which has probably not been understood.

The Lining Shell.—This shell, which has been previously described, follows the tunnel until it finally terminates in a spherical cap, which may be seen to the left of Fig. 1, Plate XV. The adult animal occasionally shrinks, and a second cap or partition may be formed as he retreats, the space between the caps remaining unoccupied.

The early portion of the tunnel, which was cut by the young animal and is now occupied by the syphon extremities, is below the normal diameter. The lining shell at this point sometimes divides itself into two tubes, each containing one of the syphons. This structure is well shown in Fig. 2, Plate XIV. It has been stated that the extremities of the syphons must be kept at the orifice of the wood. The collar and pallets recede as the animal grows larger, thus forming a considerable space between the pallets and the orifice of the tunnel, which is filled with little rings of shell, whose sharp edges serve to protect the entrance. The slender syphons emerging from the pallets pass readily through the spaces at the centers of the rings.

The teredo can rarely advance for any time in a straight line, being forced to deviate therefrom so as to pass around obstacles, such as cracks, knots or the pre-existing tunnels of its companions. The tunnels may wind in and out and pass so close to one another as to occupy almost the entire content. This fact is well illustrated in Fig. 2, Plate XV. The thickness of the lining varies with the species. It is sometimes so thin and fragile that it becomes detached by the slightest shock. Many of the dried specimens exhibited in museums do not show the lining shell for this reason. The shell is sometimes very thick. The specimen shown in Fig. 1, Plate XIV, exhibits an extreme thickness of half an inch. It was 41 ins. long and 3 ins. in diameter at the larger end. This species exists in the tropics, and does not penetrate wood, but forces its way into the sand, thus resembling the razor clam. The shells of this variety of teredo sometimes become covered with oysters or other mollusks. The lining presents a surface against which the soft body of the mollusk may press without injury. It seals the interior of the cell so that the water supply may be better controlled by the syphons.

The teredo rarely crosses a seam or joint in the wood, probably because it fears for the integrity of the lining. Specimens exhibiting the attempt of the teredo to cross a seam show that the shell has been much strengthened at the junction point. When the teredo arrives at

PLATE XV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XL, No. 837.
SNOW ON MARINE WOOD-BORERS.

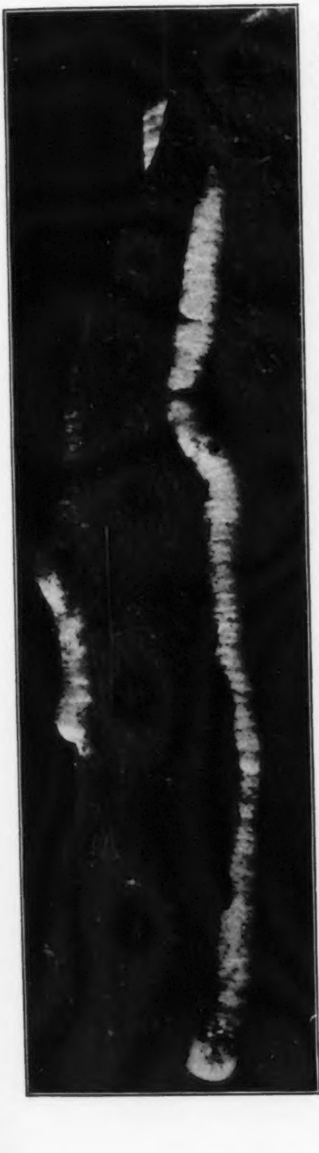


FIG. 1.—DISSECTION SHOWING LINING SHELL THROUGH WOOD. LIFE SIZE.

FIG. 3.—END VIEW OF FIG. 1. LIFE SIZE.

FIG. 2.—MASS OF LINING SHELLS. LIFE SIZE.

maturity, or whenever an insurmountable obstacle is encountered, it seals over the inner extremity of the lining. The growth of the animal. in length, is stopped in either case, and it is entirely surrounded by shell. There is a communication with the outer sea at the two syphon points only, and as the animal continues to live for some time under these conditions it is evident that its sustenance is derived from other sources than the wood.

Vital Processes.—The teredo resembles other bivalve mollusks in that it exists upon infusorial life. This food, together with the necessary amount of oxygen, is drawn in through the longer or incurrent syphon, and flows throughout the length of the animal until it reaches the mouth at the other extremity. The mouth, stomach and intestine are well developed and perform their usual offices. The oxygen is retained by the gills. The return current, beginning at the gills, removes the exhausted water, the excretions and the woody particles. These flow out through the animal and are ejected by the shorter or outcurrent syphon. The teredo does not devour wood; its form is such that dust and other débris have to pass through its body to the point of ejection. Where a teredo is watched for some time, small clouds of very fine dust may at length be observed puffed out from the orifice. The circulation through the syphons is continuous.

The teredo may live for a short time out of water. This fact explains its ability to attack wood between high and low water. The specimens which enter wood where it is exposed between the tides do not seem to be greatly hindered in their work.

Th. G. Hoech, M. Am. Soc. C. E., states* that teredos have been found alive in wood which had been removed from the water for two months. The circumstances are not stated, but it is probable that the wood was in bulk and remained moist in consequence.

Many of the logs in a cargo of Central American woods recently received in New York City, after a voyage of about two weeks, were found to be occupied by living teredos, which had gained entrance to the wood while it was waiting shipment in Southern waters. They were alive, strong, apparently healthy and able to resume their work if the wood should be again submerged. It is probable that considerable water was contained in the wood and hold of the vessel, yet the logs were certainly not submerged, and the fact remains, that these particular teredos survived the voyage and were so numerons as to

* Report on Woods Exempt from Attack by the Teredo.

emit a strong, disagreeable, fishy odor, which necessitated the removal of the logs from the yard.

R. Montfort, M. Am. Soc. C. E., states that teredos occupying standing piles were killed when these piles were encircled by loose iron jackets.* The teredos were in no wise injured by the jackets and the presumption is that the jackets were forced into the mud and that the teredos were destroyed by the muddy water. Where infected vessels are subjected to fresh water, the teredos usually live for about two weeks, so far as known.

When specimens of wood containing teredos are removed from sea water, the syphons relax after the vitality of the animal is gone. If the specimen be held upside down, the syphons then fall outward to a distance of 1 in. or more, according to the size of the animal within.

The Boring Apparatus.—While the animal is still very small, it settles upon the surface of the wood and almost immediately begins to clear away a place in which to burrow. A small pit is made by the edges of the valves of the shell, which come together on pivots shown in Fig. 2. The shells are controlled by powerful muscles acting so as to swing them backward and forward upon the pivots. Only a few of the teeth upon the shell are shown in Fig. 2, and these are exaggerated in size. When the posterior muscle contracts, the shell, with the teeth, is thrown outward and backward and rasps upon the surfaces of the wood. The process is assisted by the foot which emerges through the large blank space between the shells and performs a cupping action.

The teredo differs from many of the pholos tribe. It probably employs the inflated syphons and pallets to some unknown extent as a fulcrum. The lower portion of the animal has a large field of rotation, so that the various portions of the anterior end of the burrow can be grated away in turn. The large end of the burrow is, of course, slightly larger than the diameter of the shell. The principal work of excavation is accomplished by the shell. Many of the stone-borers, on the other hand, brace themselves by means of the shell which they open against the walls of their burrow and hold there as a fulcrum. The muscular foot emerges from the shell, and, assisted by the grit of previous borings, grinds at the stone. The wood-borers, so far as known, excavate with the shell, assisted by the foot. Xylophaga and teredina probably bore like the teredos.

* *Transactions*, Am. Soc. C. E., Vol. xxxi, p. 227.

PLATE XVI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XL, No. 837.
SNOW ON MARINE WOOD-BORERS.

FIG. 1.—SURFACE OF WOOD OCCUPIED BY TEREDOS. LIFE SIZE.

FIG. 2.—SECTION PARALLEL TO FACE OF FIG. 1. LIFE SIZE.

FIG. 3.—VERTICAL SECTION THROUGH FIGS. 1 AND 2. LIFE SIZE.

The Character of the Excavation.—The teredo is very small when it begins to attack the wood, and the hole by which entrance is made, which is the only perforation that appears upon the exterior, is very minute (see Fig. 1, Plate XVI). The animal develops very rapidly.

The adult diameter is usually attained within 1 or 2 ins. of the surface, and the burrow increases in diameter regularly from the point of entrance to the maximum diameter. The animal grows principally in the direction of length, and therefore, it attacks the wood so as to accommodate its quarters to this increase in length. The boring is first carried on across the grain, but ordinarily turns within a short distance and passes in the direction of the grain. This general direction is usually followed, but obstacles are so frequently encountered that the tunnels become exceedingly tortuous, and pass in every conceivable direction.

The teredo usually passes around knots, although quite competent to penetrate knots of oak and other hard woods. Adjoining tunnels are not encroached upon, because these tunnels are completely occupied by live teredos, and more ingenuity would be required to pass through one of them than to avoid it. When cracks exist in the centers of large timbers, they are approached from all sides, but the film is never willingly broken through. It may be assumed that the teredo does not desire to cross any crack or sign of cleavage. It prefers wood that is not surrounded by bark, because of the line of contact between the wood and the bark. When a piece of wood is thoroughly infested, the animals have to pass very close to one another, and the thin film of wood left between the adjacent tunnels is reinforced by the calcareous lining. E. L. Corthell, M. Am. Soc. C. E., states that the teredos pass through the willows of the Mississippi improvements so as to leave them a mass of nearly parallel tubes. The calcareous lining appears to lend some degree of strength and toughness to the wood thus weakened.

A fact which is of great importance is that the teredo must always command the opening of its burrow, and have free and permanent access to the water. One end of the teredo being thus fastened at the outside of the wood, the depth of penetration must be limited to the length of the animal. It cannot exist in the interior of woodwork, nor can it live or breed without actual contact with free water. A report that a teredo had been found in the interior of one of the

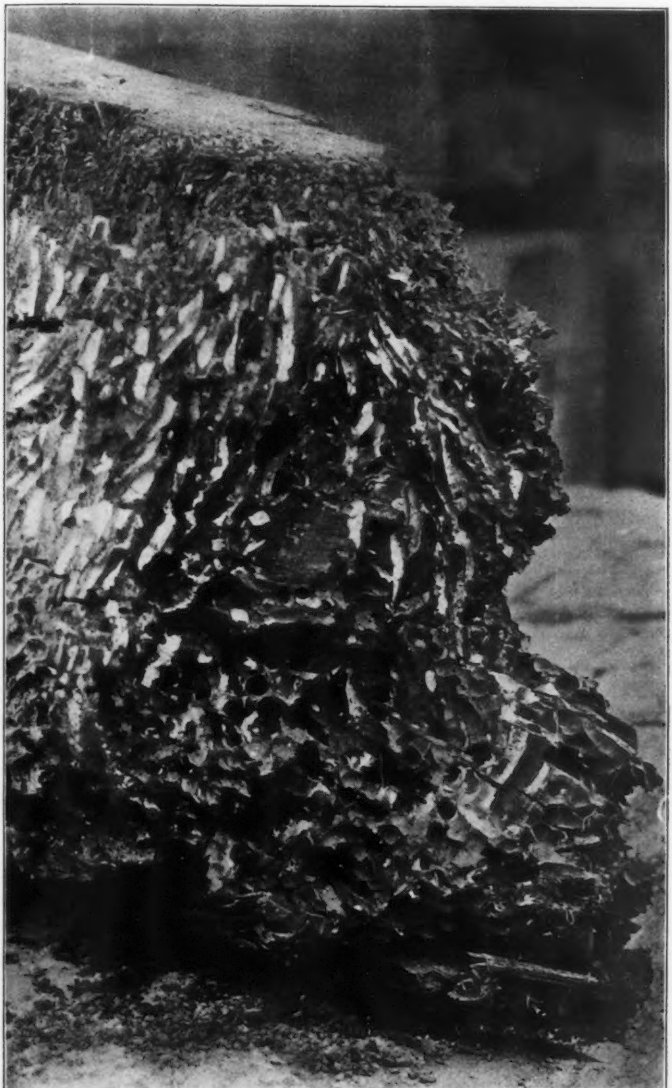
caissons of the Brooklyn Bridge was the cause of much popular and unwarranted excitement at the time of the erection of that structure.

It is impossible to examine the work of the teredo without surprise at the smooth surface of the burrow, which is cut as perfectly as by the sharpest chisel. In still weather the teredo may be plainly heard while at work. More than 50% of the weight of the wood may be removed by the teredo, without being greatly evidenced upon the surface. The little holes by which the animal gains entrance become partially obliterated when it dies. Wood may appear to be quite sound and yet be so weakened that much of it can be crushed by the hand (see Plate XVII). Failure, therefore, frequently comes suddenly. The tops of piles which appear to be in good condition are suddenly seen floating away. A large wharf at Provincetown, Cape Cod, unexpectedly collapsed by reason of the teredo. A freight train on the Louisville and Nashville Railroad crushed through a trestle which had been standing but ten months, and had been constantly inspected without showing signs of weakness. An examination showed that the piles in this instance had been eaten off close to the mud line.

Plate XVII is from a photograph of a log of Panama mahogany, which was cut in the uplands of the Isthmus and floated through fresh water to the harbor of Colon, where it remained floating in salt water while awaiting shipment. The log was overlooked for one season, and the work of the teredo is thought to have been accomplished in about nine months. The heavy, wet specimen was shipped with others, under the impression that it was sound, but it broke by its own weight after its arrival in New York.

The Size of the Teredo.—The size of the teredo depends upon the species, locality and age, and the absence of obstacles to excavation. Specimens of wood submitted for examination are frequently divested of any signs by which the excavators can be classified. The excavation can be identified as the work of the teredo, but the exact species accountable for the work cannot always be told.

Locality has much to do with development. Specimens grow more rapidly and attain larger size where the climate is warm. The teredo continues to grow until it reaches its maximum size, unless an obstacle is encountered. The species Navalis may be assumed to average from about one-fourth to three-eighths of an inch in diameter and from about 10 to 15 ins. in length, but specimens of the teredo frequently attain a



PANAMA MAHOGANY, DESTROYED IN ONE SEASON.

much greater size. Professor Siegerfoos writes that he has measured them up to 4 ft. in length and that the specimens thus measured had not arrived at their full limits. A log about 2½ ft. square, recently examined, was found to be entirely honeycombed, the borings starting from opposite sides and passing slantingly into the wood, so that they probably averaged over 2 ft. in length. The specimen was of particular interest because the destruction had been accomplished in a single season.

The minimum diameter and length of a boring may be taken as ¼ in. and 5 ins. respectively. The maximum length may be taken as 4 ft. The largest diameter ever noticed by the author measured 1⅛ ins.; this is shown on Plate XVIII. After the teredo has penetrated the wood for a little distance, the diameter remains about constant. Diameters are measured in this portion of the burrow and not at the entrance.

The Range or Field of Work.—The teredo operates throughout a vertical field of considerable depth. This field begins at a point a little above low-water mark, and extends downward until the pressure becomes too great, or the soil at the bottom is encountered. The teredo seems to be able to exist for a little time without submergence, and is therefore able to live above the low-water mark, although exposed daily between the tides. The interior extremity of the tunnel may be higher up than the entrance. The upper limit of the excavated wood cannot be determined by an examination of the orifices at the surface. The lower limit is uncertain and is probably different for different species. It has been assumed by many that the lower limit could be set at about 14 ft. below low water, but recent information, thought to be reliable, indicates that piles have been affected at a depth of from 20 to 25 ft. below that level. The fact that the interior extremity of the burrow is often found below the mud line has given the impression that the field of the animal may extend below this limit, but the outside opening or entrance made by the teredo is never below the soil, although the boring may turn downward for the whole length of the animal. If sediment accumulates around the bottom of the wood so as to cover the syphons, the death of the teredo results.

It is reported that in some harbors the teredos attack at the surface, and in others at the mud line. These differences are partially

due to differences in the constituents of the upper and lower layers of water. Where the fresh water of a river meets the heavy water of a sea, the teredo may be almost entirely confined to the lower stratum. The range or field of the teredo is important, because protective processes which could be confined to this field would be more economical than those in common use which are applied to the entire structure.

The Rapidity of the Work.—The rapidity of the work of the teredo depends upon conditions similar to those which govern its size. The evidence upon this subject is not always accompanied by a statement of the conditions under which the results were accomplished, such as the species of teredo, the character of the wood, the season, the climate and the depth of submergence, all of which are points as important as the geographical location of the work. The period in which the teredo accomplishes its work is variable. It may be six weeks or as many years, but rapid work is usually accomplished under the conditions which exist in warm climates.

Impure water and cold weather retard its activity, while pure or warm water expedites the work. Maximum probabilities being more important than minimum possibilities, it is safe to assume that a 6-in. boring may be driven in six weeks, and hence, as the animal attacks all sides, a pile 1 ft. thick may be destroyed in that period.

A young teredo has been found in wood which has been submerged for eight days[a]. Six-inch piles have been destroyed at Aransas Pass in six weeks[b], while other piles in the same locality have lasted for three or four months[c]. "Piles have been rendered useless by a submergence of one hundred days in Mobile Bay." On the Louisville and Nashville Railroad piles 12 x 15 ins. frequently have to be replaced after six months' service[d]. Unpainted spar buoys have a life of about one year in the vicinity of Cape Cod[e]. Piles have been destroyed in the harbor of Galveston in three years[f]. They have lasted twelve years in the Delaware Breakwater Harbor[g].

Reproduction and Development.—Mollusks produce their young by means of eggs. Those of the teredo are spherical in shape and

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[a] U. S. Annual Report of Scientific Discovery for 1857.
[b] Report, Chief of Engineers, U. S. A., 1888, pp. 13, 14.
[c] Annual Report, Chief of Engineers, U. S. A., 1879, p. 937.
[d] Montfort, *Transactions*, Am. Soc. C. E., Vol. xxxi, p. 221.
[e] Report to U. S. Fish Commission, by Capt. Edwards.
[f] Report, Chief of Engineers, U. S. A., 1868, p. 512.
[g] Annual Report, Chief of Engineers, U. S. A., 1871, p. 667.

UNUSUALLY LARGE PERFORATIONS.

greenish yellow in color. The animal is exceedingly prolific; the eggs of a single specimen being probably numbered by the million. The eggs are first deposited in the gill cavity, and are almost at once fertilized. They are free-swimming at the end of three hours, have a well-developed shell before the end of the day, are very hardy, and all seem to be fertilized and to develop.

The embryo passes through several interesting stages before it assumes the character and form of the adult. It is first covered by fine hairs or cilia, which enable it to swim. These are soon lost, and the rudiments of a small bivalve shell appear, which is at first heart-shaped and very small, yet large enough to enclose the entire animal. The portion of the body which protrudes from the shell is fringed with cilia. These, again, constitute swimming organs, and the teredo swims actively until a piece of wood is encountered. The shell has now become rounder, and organs of sight and hearing have been developed. The appearance of these organs marks a climax in the life of the young animal, and it begins to elongate. The locomotive cilia disappear, the eyes are lost, and the mature form is gradually assumed. The life of the larvæ is about four weeks, during all of which time they are free swimmers. If the animal has become attached to wood, however, its energies may be expended thereon. The life of a specimen which has not found any wood to attack has not been determined, but is probably quite short.

The results of some observations by Professor Siegerfoos upon the Xylotrya Fimbriata at Beaufort are thus summarized: *

"The free-swimming stage is reached in three hours, and a well-developed shell is formed in a day. We have no direct observations as to the time the ship larva is free-swimming. We may assume, I think, that it is at least a month, or it may be two. Most of its energies are devoted to locomotion during this period, but, after it has attached itself, all of its energies are devoted to forming its burrow and securing its food. Coming in contact with the wood, the larva throws out a single, long byssus thread for attachment and never again leaves its place. The newly attached larva is somewhat less than .25 mm. long. In twelve days, it has attained a length of 3 mm. In sixteen days, 6 mm. In twenty days, 11 mm. In thirty days, 63 mm. In thirty-six days, about 100 mm., when it bears ripe eggs or sperm."

The extreme life limit of the teredo is unknown, but it is thought that under favorable conditions the animal may live for several years.

* Johns Hopkins Circular, 1896.

In the vicinity of New York the processes of reproduction take place for the most part in May. They are not entirely confined to that month, however, but may extend throughout a greater part of the summer. Reproduction in tropical countries is probably extended throughout the entire year. The animal may develop to a very large size, and may possibly attain maturity in a single season.

The Effect of Climate, Temperature or Water.—The Teredo Navalis thrives best under the influence of heat, but, notwithstanding this fact, it can resist cold to a considerable degree. It is not active when subjected to low temperatures, yet it can endure them. Some species of the teredo have been reported as far north as Eastport, Me., and they exist abundantly under such conditions as obtain at Cape Cod. Destruction is not carried on as continuously or as rapidly in cold climates as in warmer ones, and for this reason maximum results are seen along the South Atlantic and Gulf States and on the Pacific Coast, where the conditions are more favorable, and where reproduction is continued during a longer period.

The syphons of the specimens observed by the author contracted when the water became cold. Only the extremities could be seen when the temperature was about 45 degrees. The syphons expanded as the water became warmer, and were fully extended after several days of continued warm weather. The incurrent tube was stretched out in one instance to a distance of nearly 2 ins. The photograph (Plate XIII) was taken at this period. It is supposed that the work of excavation is not as active when the syphons are withdrawn.

The purity of the water should be considered in connection with the work of the teredo. Some species inhabit pure sea water; some prefer brackish water; others abound in waters that are muddy, while others again live only in waters that are clear and pure.* The teredo is often present in certain waters, yet absent in others nearly adjacent. This is usually due to some difference in the water. The Xylotrya Fimbriata seems to be able to survive the brackish, impure water of the inner New York Harbor, while other species could not live there, though they are present in the nearby outer ocean. The teredo is very active on the North Pacific Coast, yet is absent near the mouth of the Columbia, where the ocean is influenced by the outflow from the river.

* Percival Wright describes a kind of "ship worm" called *Nausitora Dunlopei* found in India, 70 miles from the sea, in perfectly fresh water.

An interesting incident is reported by a reputable firm in New York City. A vessel carrying hard-wood logs was wrecked in the vicinity of the Gulf of Mexico on a sandy beach separating the ocean from a river. The logs were thrown into the ocean, and were afterward beached and conveyed over the sand to the sheltered water of the river, where they remained about six weeks. The wood was rapidly affected as soon as it reached the brackish water of the river, the results being so noticeable that some of the borings were measured, and are said to have averaged 6 ins. in length. The wood which remained in the outer water was not injured.

It is stated that the Russians once built a large dock in the harbor of Sebastopol, and surrounded it with fresh water in the hope that it would be thus protected from the mollusks which infected the harbor; but it was found that the teredo destroyed the wood as rapidly as when it was submerged in salt water. The discrepancy indicated by these incidents may be accounted for by the difference in the species. The teredo which avoids the brackish water at the mouth of the Columbia differs from that which prefers it in the harbor of Sebastopol or in the river near the Gulf of Mexico.

The effect of the condition of the water upon the teredo is interesting. The opinion that the periods of unusual prevalence in Holland were in some way connected with a change in the quality of the water was expressed as early as 1733, and since that time has frequently been endorsed by Dutch engineers. Dr. von Baumhauer, Holland Commissioner to the Centennial Exposition has called attention to the fact that but little rain fell in the years when the teredo was so unusually prevalent, hence the smaller volumes of river water were thought to have permitted larger proportions of salt to reach the coast. This theory is strengthened by the fact that analyses showed a variation in the proportion of salt during dry and rainy seasons.

The Distribution of the Teredo.—The Teredo Navalis has been identified as existing in the United States between Florida and Cape Cod, and in Europe, from Sweden to Sicily. The *Teredo Norvegica* has been found from Cape Cod northward to the coast of Maine. The *Teredo Megotara* has been found in floating pine wood at Newport, R. I., and in cedar buoys, etc., at New Bedford, Mass. It has been found south as far as the coast of South Carolina. The *Teredo Dilatata* occurs from Massachusetts Bay to South Carolina. The *Teredo Thompsoni* has

been found at Cape Cod, Mass. The *Xylophaga Dorsalis* inhabits the waters of the North Atlantic. The *Xylotrya Fimbriata* is found along the Atlantic Coast from Long Island Sound to Florida. It also abounds in the waters of the North Pacific, and is one of the European forms.

Different species of the teredo are notably present in such localities as the Bermudas, Jamaica, New Zealand and Australia. The teredo, as a rule, may be generally found in the Tropics, and is hardly less numerous in many of the northern waters.

Woods Affected by the Teredo.—All varieties of wood commonly used in construction are subject to attack when exposed to the teredo. Immunity is occasionally claimed for some particular wood, but it will generally be found that the claims have been based upon local conditions and are not fully substantiated.

The only woods about which any doubt may be felt are those which contain some gum or bitter essence and those which have a porous structure ; and of these the majority are not well known to American constructors. Some of them undoubtedly possess merit as far as they have been tested, but others may be regarded as open to doubt, and it is an error on the safe side to assume that none are exempt under all conditions. A wood about which less doubt may be felt than any others is the Australian Jarrah. This is a variety of Eucalyptus which is much relied upon in Australia, but it is understood that it has failed in Ceylon, New Zealand and elsewhere. It is very possible, however, that the wood used at the works in question was not the Jarrah.

Karri wood is another form of Eucalyptus, the history of which is much less certain than that of the Jarrah, with which it is often confused. Both varieties are now being extensively introduced into Europe for street-paving purposes. It has often been held that Teak wood is exempt, but the evidence is against it, as Teak wood logs affected by the teredo have been received in New York City within a comparatively recent time.

The following list of partially exempt woods has been compiled by Mr. T. A. Britton from authorities which are said to be reliable:* (Western Australia) Jarrah, Beefwood and Tooart; (Bahama) Stopperwood; (Brazil) Sicupira, Greenheart; (India) Malabar Teak., Sisso,

* Treatise, "Dry Rot in Timber," p. 223

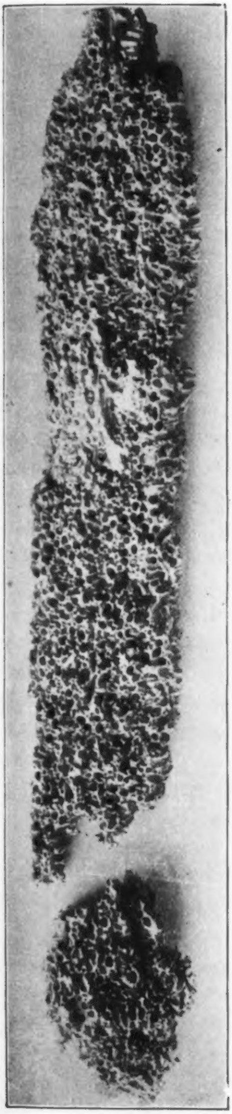


Fig. 1.—Surface of Wood attacked by Limnoria. Life Size.

Fig. 2.—Limnoria from Specimen shown in Fig. 1. Life Size.

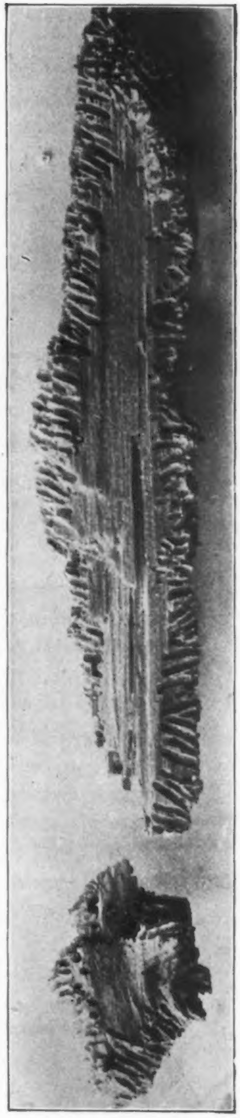


Fig. 3.—Showing depth of Holes. Life Size.

May-Tobek; (South America) Santa Maria Wood; (Tasmania) Blue Gum; and (West Indies) Lignum Vitæ.

It is not urged that these are entirely exempt, but that they have been exempt for long periods. Very few of them are widely known in construction. It is understood that at Southampton some greenheart piles have failed recently.

A commission, appointed in Holland to investigate this question, decided that—

"Although we do not know with any certainty if among the exotic woods there may not be found those which resist the teredo, we can affirm that hardness is not an obstacle that prevents that mollusk from perforating his galleries."

This conclusion is well borne out by the experience with the Iron Bark tree, the Eucalyptus Lencoxylon, of Australia. This wood has a very great tensile strength, and the crushing strength is said to be "nearly one-fourth that of iron." The wood is certainly very hard, and yet the teredo is by no means repelled by it.

The Eucalyptus Globulus, or Blue Gum, has been successfully introduced into the United States, and is grown in California and Florida. Some hopes have been expressed that this wood might be useful for marine purposes, but they have not been realized. Cedar has repelled the teredo for some little time in the harbor of San Francisco, and it is stated that some species of the Black Mangrove in Jamaica are exempt.

The Osage Orange, or Bodark, has been used to some extent in the Gulf States. It is understood that this wood is relied upon principally because it is hard.

A much greater reliance may be placed upon structure than upon the presence of foreign substances. The teredo desires a compact wood for its abode, and does not like cracks or loose structure. Endogenous trees, palms, for instance, are probably exempt to a greater or less extent. The wood of the latter consists of a mass of thick fibers so independent of one another that brushes can be made by rubbing one end of a stick until the fibers become detached and appear like bristles. Considerable reliance may be placed upon the Cocoa Palm of Mexico, the King Palm of Cuba, and the Cabbage Palm or Palmetto of Florida.

It may be assumed that the conditions of impregnation or structure necessary to repel the teredo do not exist naturally in such woods as

are commonly used in engineering works. It may also be assumed, so far as known at present, that partial or complete immunity, as applied to such woods as are in common use, is a question of locality rather than of variety of wood.

THE LIMNORIA LIGNORUM, WHITE.

This small crustacean has several names, as the Limnoria Terebrans, the Gribble and the Boring Gribble. The limnoria has not been studied for so long a period as the teredo. It was first noticed by Robert Stevenson in 1810, and was examined by Dr. Leach, who one year later pronounced it a new species. It has been investigated since that time by numerous European writers, and, in the United States, it has been studied by Dr. Verrill, of Yale University, and Dr. Sidney I. Smith, of the United States Fish Commission.

The limnoria is gregarious and is found, if at all, in large quantities. It is much smaller than the teredo, but it exists in greater numbers. It has been traced from New York northward to the Bay of Fundy, and large numbers exist in the North Pacific Ocean. It is a very familiar and destructive form of life in Europe. If the destruction accomplished by the limnoria could be estimated it would be found to be surprisingly great.

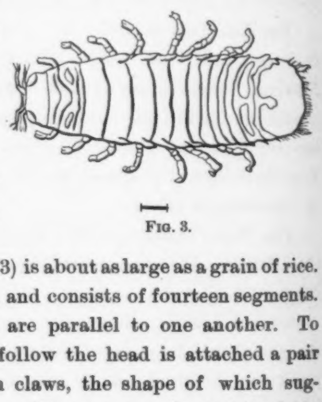
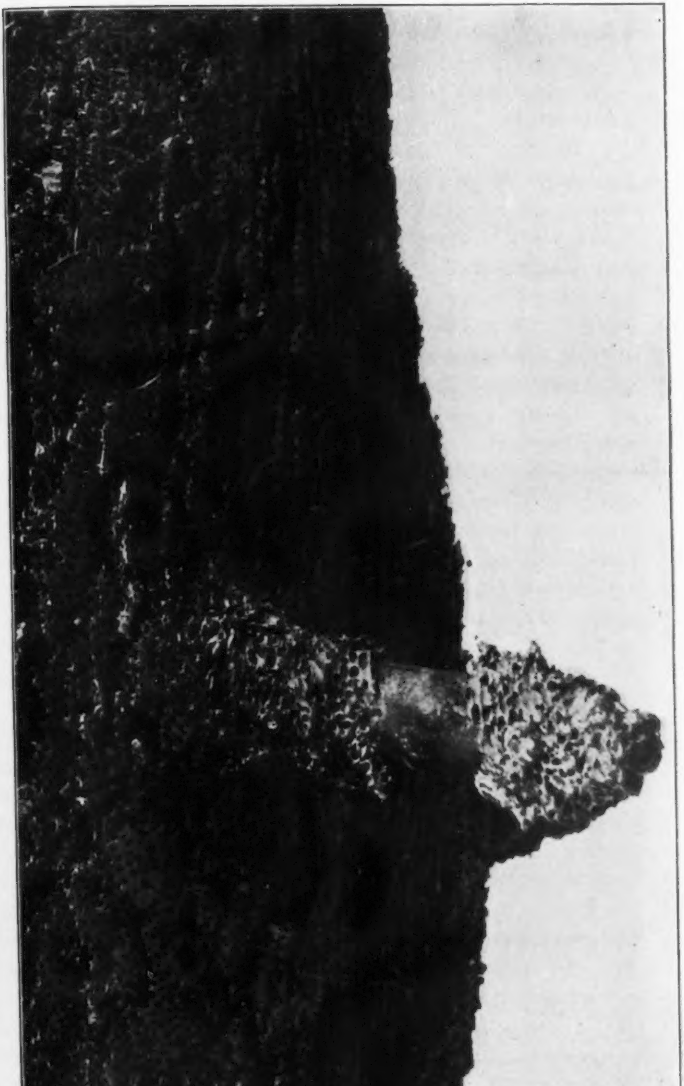


FIG. 3.

Descriptive.—The limnoria (Fig. 3) is about as large as a grain of rice. The body is flat, round at each end, and consists of fourteen segments. The sides are nearly straight and are parallel to one another. To each of the seven segments which follow the head is attached a pair of short, stout legs terminating in claws, the shape of which suggests the small claws of the lobster. The upper surface of the body is covered with small hairs to which more or less dirt usually adheres. The body is grayish in color, and sometimes resembles the color of the wet wood so much that it is difficult to distinguish it. The limnoria can swim, creep backward and forward, as well as jump backward by means of its tail. When touched, it rolls itself into a ball, and in this particular, as well as in general appearance, it resembles the common sow bug.



PILE FROM PUGET SOUND, SHOWING WORK OF LIMNORIA. LIFE SIZE.

Vital Processes.—The limnoria differs from the teredo in that it is a vegetarian. The teredo is sustained by infusorial life, but the limnoria devours wood. Its tunnel affords both food and shelter.

Boring Apparatus.—The limnoria attacks the wood by means of its mandibles or claws. It prefers wet wood and succeeds in making a very clean-cut excavation.

Character of the Excavation.—The work of the limnoria differs from that of the teredo in that it works upon the surface of the wood in such a manner as to be clearly seen, while the work of the teredo is usually concealed until the failure of the wood. The limnoria is similar to the teredo in that its tunnel must communicate directly with the salt water; hence neither of these animals can live in the interior of thick woodwork, such as that of a caisson. The limnoria makes a small, round, parallel-sided tunnel through which it can pass freely back and forth from the sea. The diameter of the entrance of the tunnel is similar to the average diameter. The tunnels are quite short, and are placed very close together (see Plate XIX). They are so numerous that the wood is rapidly reduced to a series of very thin partitions, which soon decay or are washed away by the waves, thus exposing a fresh surface which is at once attacked. Layer after layer is thus rapidly removed, so that the timber is destroyed in a very few years. The limnoria frequently works in conjunction with the teredo, attacking the exterior while the teredo destroys the interior of the wood, and this combination effects a rapid destruction.

The limnoria attacks both the hard and soft parts of the wood. The hard annual layers have not been avoided in the specimens examined. The limnoria can penetrate knots, but frequently avoids them, so that these hard portions stand out in relief as the timbers waste away. Iron rust is said to cause a somewhat similar effect.

The Size of the Limnoria.—The limnoria is very small, but notwithstanding this fact, it is very destructive. The multitude of these animals compensates for their size. It may be assumed to be from $\frac{1}{6}$ to $\frac{1}{4}$ in. in length, and about $\frac{1}{16}$ in. in diameter. The tunnels are about $\frac{1}{2}$ in. in depth.

The Range or Field of Work.—The wide range observed between the several species of the teredo does not apply to the limnoria. Its work, as observed in the United States, is generally confined to a limited distance above and below the low-water mark. Where the varia-

tions of the tides are extensive, as in the vicinity of the Bay of Fundy, the range of the limnoria is correspondingly great. The United States Fish Commission states that it has been found, although rarely, as deep as 40 to 60 ft.

The Rapidity of the Work.—The limnoria does not work as rapidly as the teredo. The number of individual workers may be taken as a measure of the work they accomplish. The number of tunnels is more important than their depth. Limnoria are almost invariably found in large numbers and destroy a layer from ¼ in. to 1 in. in thickness in a year, the average yearly destruction being probably ½ in.

Almost all wood used in marine locations is in the form of piles, which are necessarily exposed upon all sides. Their effective diameter may be reduced at the rate of 1 in. for each season, which result, while not equal to that accomplished by the teredo, is sufficient to cause a great loss.

The Effect of Climate, Temperature and Water.—The limnoria is found where the coldness of the climate prohibits the existence of the teredo. It requires pure sea water, and cannot exist in fresh or in impure water, consequently it is not found at the mouths of rivers.

The Distribution of the Limnoria.—The animals are distributed along the American coast from Florida to Nova Scotia. They exist sparingly in Long Island Sound, but are quite numerous upon the coast of Massachusetts, and are very destructive in the Bay of Fundy. They are very active along the North Pacific coast, and are much feared in the vicinity of Puget Sound and the Straits of Fuca. They exist also in abundance upon the coast of Great Britain and in other parts of Europe.

Woods Affected by the Limnoria.—The limnoria seems willing to attack all varieties of wood commonly used by American constructors, but is said to prefer soft woods. It has been known to attack the gutta percha of submarine telegraph cables. It is said that teak wood is free from attack. Plate XX is a life-size photograph of part of a piece of wood from Port Townsend, Wash., showing the work of the limnoria.

Sphæroma Destructor (Richardson).

Attention has recently been called to this hitherto undescribed form of life. This animal is interesting in that it is active in comparatively fresh water. It resembles the limnoria in that it attacks the wood

FIG. 1.—WORK OF DESTRUCTOR.

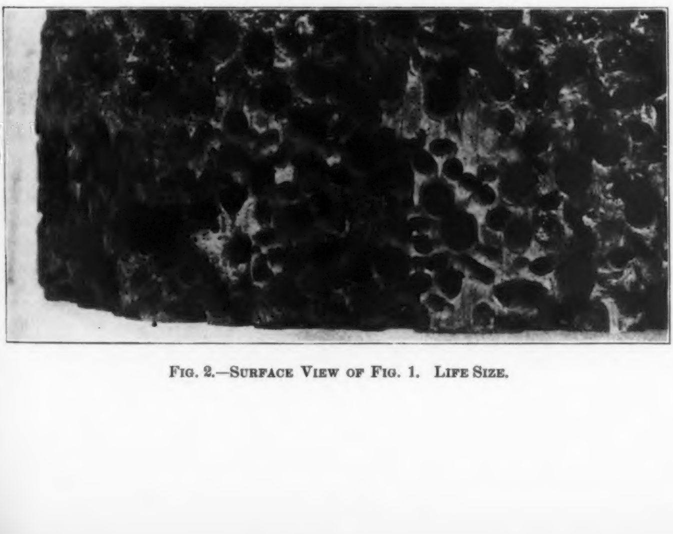


FIG. 2.—SURFACE VIEW OF FIG. 1. LIFE SIZE.

from without, the interior of the wood being unaffected while the exterior is being destroyed.

The work of these animals was first noticed upon some of the trestles of the Florida East Coast Railway, in the vicinity of St. Johns River, in Putnam County, Florida. Specimens of the wood were submitted to the Carbolineum Wood Preserving Company, of New York City, and were referred by them to the Smithsonian Institution at Washington, where they were studied by Miss Harriet Richardson.*

The animal somewhat resembles the limnoria in appearance, and is dark brown in color. It works between high and low-water marks. These are not tidal levels, but changes due to the wind assisted by the tides. The water appears to be quite fresh and the water hyacinth, which is not commonly found in salt water, flourishes in the vicinity. The distance to the ocean is about 100 miles.

The diameter of the long-leafed yellow pine pile, from a photograph of which Plate XXI was prepared, is said to have been reduced from 16 ins. to $7\frac{1}{8}$ ins. in eight years.

Several forms of fresh-water shipworms (some very large) have been found in Australian rivers.†

The Chelura Terebrans.

This animal was first noticed at Trieste in 1839, and was next found in some piles in the harbor of Kingston. The Irish specimens were described by Professor Allman in 1847.‡ The chelura was not identified in America until 1875, when two small specimens were discovered by Professor Sidney I. Smith at Wood's Holl, Mass. No others were observed until August, 1879, when Professor Verrill discovered a number of them in some piles at Provincetown, Mass. The chelura unquestionably belongs to the amphipods, and there is apparently but one species of the genus. The C. Pontiac described by Czerniavski in 1868 is identical with the Chelura Terebrans.

Descriptive.—The general appearance of the chelura (Fig. 4) resembles that of the ordinary shrimp, and for this reason is sometimes referred to as the wood shrimp. Its shape differs from that of the limnoria in a very striking degree. The two animals resemble one another only in size. The chelura is a very active little animal, and

* Paper before the Biological Society of Washington, D. C., May 13th, 1897.

† Charles Hedley, F. L. S., Sidney, Australia.

‡ Ann. and Mag. Nat. Hist., xix, 1847, p. 361.

swims upon its back. It is a jumper, and can project itself to a considerable height when placed upon dry land, and in this respect resembles the sand hopper. The body is semi-translucent, and is thickly spotted or mottled with pink. The animal is distinguished by three pairs of caudal stylets, the last of which are nearly as long as the body. Those of the females or the young animals are not so long.

Vital Processes.—The chelura resembles the limnoria in that it is a vegetarian, and its burrow affords both residence and food. The fact that the chelura devours wood for sustenance is proved by the minutely divided ligneous matter found in the alimentary organs of dissected animals.

Boring Apparatus.—Professor Allman's original study of the chelura is in part yet regarded as authoritative. He states that the chelura attacks the wood and reduces it to minute fragments by means of a kind of file.

The Character of the Excavation.—Great difficulty has been experienced in obtaining specimens of the work of the chelura, and those obtained are not sufficient to warrant many generalizations. In many particulars the work of the limnoria and of the chelura bear such a close resemblance as to lead to the suspicion that

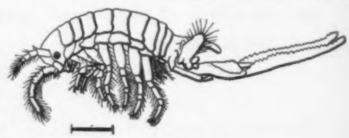


FIG. 4.

these animals are sometimes confused with one another. The excavations of the chelura are slightly larger than those of the limnoria, but are conducted in much the same manner, as the wood is attacked entirely from without. Numerous punctures are made, and then the weakened layer succumbs to the action of the waves, the surface thus exposed being in turn attacked and the wood destroyed in the same manner. It is stated that the excavations of the chelura are more oblique in their direction than those of the limnoria, and this is certainly true of the specimens observed.

The chelura appears to prefer soft wood, and their attacks are made as much as possible in the softer annual rings. The tendency toward an arrangement of perforations in lines is shown in Plate XXII. The work of the chelura differs from that of the limnoria, in that the latter attacks the wood at any available point, while the chelura, on the contrary, prefers the softer portions, and avoids the hard wood

PLATE XXII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XL, No. 837.
SNOW ON MARINE WOOD-BORERS.

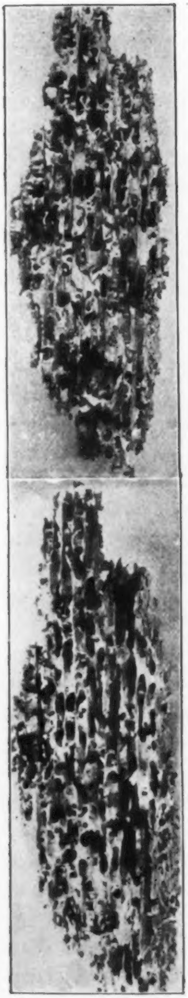


FIG. 1.—SURFACE APPEARANCE OF WOOD ATTACKED BY THE CHELURA. LIFE SIZE.

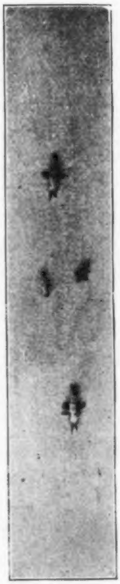


FIG. 2.—LIMNORIA FROM SPECIMEN SHOWN IN FIG. 1. LIFE SIZE.

FIG. 3.—SECTION OF SPECIMEN SHOWN IN FIG. 1. LIFE SIZE.

around knots. Perforations found in such localities may be assumed to be the work of the limnoria.

The chelura and limnoria are associated with one another in the American localities which have afforded specimens of the former. The perforated wood from these localities shows that the limnoria were in the timber in advance of the chelura. It also shows larger individual chelura confined to the soft rings. These facts indicate that young chelura may at first follow limnoria through the hard rings, but that as they increase in size, they turn toward the soft wood. They obviously attain full size in the larger tunnels. The individual chelura appears to be even more formidable than the individual limnoria.

The Size of the Chelura.—The chelura is somewhat larger than the limnoria. It is said that specimens one-third of an inch in length have been measured.

The Range or Field of Work.—The frequent confusion between these two animals, together with the lack of American data, leaves the question of range unsettled. The specimens found at Provincetown were all taken from wood submerged from 8 to 12 ft. below low-water level.

The Distribution of the Chelura.—The chelura was sought many times along the American coast between New Jersey and Nova Scotia, but was not discovered until 1875. It is yet confined, so far as known, to the two original localities, Wood's Holl and Provincetown, both in Massachusetts, but it is more than possible that the animal has escaped observation, and that it is common on the North Atlantic coast. The unskilful eye would readily confound the chelura with the limnoria, although the two animals belong to distinct divisions of the crustaceans. It is quite possible that some of the damage hitherto ascribed to other animals has been accomplished by the chelura.

The chelura has been reported at many places on the coast of Europe, and is mentioned as existing from South Norway to the Adriatic. Attention has been called to the extent of its range. It is said to be an inhabitant of Australia.* In Europe a very great amount of destruction is attributed to this species, and efforts have been

* Since the above was written Mr. Charles Hedley has ascertained "that not only are Chelura and Limnoria not included as Australian pests, but that neither are known to exist in Australian waters. We have, however, kindred forms which take their place and do their work."

made to substantiate these points, but have thus far been unsuccessful. It may be that some European results, attributed to this animal, are deserved by the limnoria, as it is probable that some of the work of the limnoria in America should be attributed to the chelura, and it is more than probable that the animals are frequently associated. Efforts to discover particular works affected exclusively by this form of life in Europe have not thus far met with success. The chelura has earned a most unenviable reputation in Europe, but it is not known in which places it exists as a specimen and in which as a pest.

Sphæroma Vastator.*

This species was found in the woodwork of a railway bridge on the west coast of the Indian Peninsula. It is said that it honeycombs the wood with cylindrical holes.

The Pholos.

A description of the pholos may suitably accompany any mention of marine wood-borers. This animal does not attack wood, but penetrates the hardest stone, and is therefore interesting because it illustrates the power of boring animals.

The pholos and the teredo are nearly related. The former differs from the latter in that its shell is much larger and in form more closely resembles the long clam. Some species of this animal are much prized by the French as table luxuries. Others are used as food on the North Pacific Coast. The pholos is an inhabitant of many seas; it is plentiful in the English Channel, and is found in many places on the American coast. The borings of the pholos are instructive, from a geological point of view. The so-called Temple of Seraphis, near Naples, affords a prominent illustration of the movement of the earth's crust. This temple has sunk in the water and has then arisen again, the fact of submergence being made clear by the perforations of the pholos. The three principal columns are honeycombed up to a height of about 10 ft., which shows that the ocean once covered the columns to that height.

The method of excavation has already been described in comparison with that of the teredo. The pholos opens its shell so as to brace itself

* Described by Mr. Spence Bates in the Ann. of Nat. His., Vol. xvii, 1886, pp. 28-31.

FIG. 1.—PHOLOS. EXCAVATING SANDSTONE. LIFE SIZE.

FIG. 2.—DACTYLUS, EXCAVATING GRANITE. LIFE SIZE.

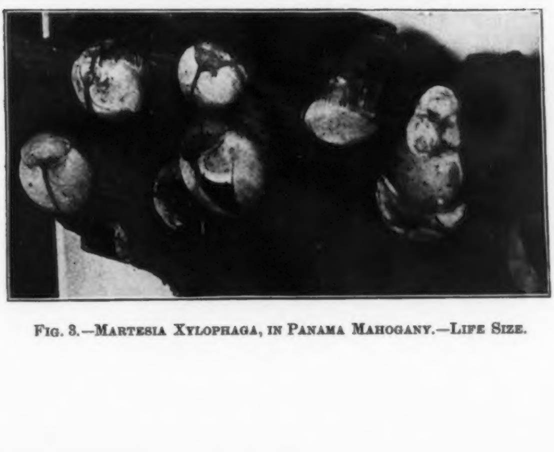


FIG. 3.—MARTESIA XYLOPHAGA, IN PANAMA MAHOGANY.—LIFE SIZE.

against the sides of its tunnel. The long foot or pestle, which is similar to that of the teredo, emerges and rubs at the surface of the stone. It is assisted by the particles of sand or rock. The cavity is thus enlarged to accommodate the growing animal. Fig. 1, Plate XXIII, shows one of the numerous species of this animal at work upon a piece of sand-stone. Fig. 2, Plate XXIII, shows a similar animal perforating solid granite; while Fig. 3, Plate XXIII, exhibits another form, found in hard wood.

The series of marine stone-borers is very great, and includes the numerous species of the pholos family, together with other animals not related to them. One of the animals of this class is a powerful enemy of the oyster industry. Another of them destroyed in one year a cargo of marble which had been wrecked in the North Atlantic.

Barnacles.

The barnacle does not perforate wood, but usually attaches itself singly or in clusters to floating or submerged wood, and does not injure it. It is removed from the bottoms of ships because it impedes their progress. Barnacles protect the surfaces they cover. The white blotches on Fig. 1, Plate XVI, show the places where barnacles were at one time attached. Fig. 3, Plate XIV, shows the form of the barnacle.

Methods of Protection.

A history of the attempts to preserve wood from the attacks of wood-borers would be voluminous. It is only necessary to call attention to those methods which have been attended with more or less success. Most of the attempts in this direction have been made with the idea of protecting wood from the attacks of the teredo. It happens, fortunately, that any method insuring immunity from the teredo secures wood from other wood-borers as well. The methods which have been used may be classified as follows:

Removal During the Breeding Season.—This method may be used to protect such objects as buoys, bathing-houses and row boats. It is only applicable where the breeding season is short as it is in the North.

A Change of Water.—Wooden vessels which have been attacked by the teredo are sometimes hauled into fresh or muddy water. The animals which have gained entrance to the wood are killed by this

means. The suggestion has been made that expensive wood-work subjected to the teredo be surrounded by fresh water.

The Use of Selected Woods.—The few varieties of wood for which claims in this particular have been made are not widely known or employed, and it is seldom urged that any are permanently exempt. Repeated attempts have been made to discover some wood upon which reliance could be placed, but with meager results. The evidence, thus far, is in favor of the palm and the Australian jarrah wood.

External Coatings.—Many of the protective methods may be grouped under the head of external coatings, one advantage of which is that the treatment may be limited to that portion of the wood which is exposed to attack, while those parts which are below the mud line or above high water need not be considered. This is not the case where internal treatment is used.

(*a*) The bark is sometimes left upon the wood, and, as long as it remains intact, protects it from the teredo. This is explained by the reluctance of the teredo to cross seams. The bark is soon loosened and removed by the waves, however, and the wood is then exposed. It is doubtful whether bark serves as a protection against the limnoria and chelura.

(*b*) Thin plank, joined closely upon the surface of the wood, will preserve it from the teredo during the existence of the plank, but affords no protection from limnoria or chelura, for the plank is soon honeycombed or loosened and the interior woodwork is then exposed to attack.

(*c*) Metallic sheathings, such as copper and zinc, have been successfully used in many places, and the former has proved to be one of the most valuable methods of protection when placed upon piles so that when they are driven home the metal extends below the mud line and up to or above high-water mark. It is used upon the bottoms of wooden vessels and is much superior to zinc, which is quickly acted upon by the salt water. Metallic coatings are expensive, but are very effective, however, in protecting against all forms of marine borers. Surfaces sometimes become coated with barnacles and similar animals which afford further protection to the wood.

(*d*) Teredo or "worm" nails have been extensively used,* and are said to have originated with the Romans. They have short spikes

*The Dutch use them to a height of one-half tide.

and large, flat and sometimes square heads. They resemble ordinary carpet or upholsterers' tacks, and are driven close together. According to the specifications adopted by the Dutch Waterstaat, the nails must be well forged and not brittle. The diameter of the head must be 3 cm. and the length of the tack 4 cm. One kgr. is to contain from thirty to thirty-four nails. An interesting series of experiments with teredo nails has been conducted by the New York Department of Docks.* Teredo nails are apt to rust and thus cause failure. It was once held that the iron rust impregnation assisted in repelling the teredo, but this appears to have more foundation of truth as regards the limnoria.

(*e*) Paints, verdigris, paraffine, tar, asphalt and other mixtures have been used as protectives, but it is usually difficult to retain such coatings in position. Mixtures which withstand the softening effect of sea water are likely to be removed by erosion, and surfaces should be inspected at least once a year.

(*f*) Attempts have been made to combine paint mixtures with some fabric such as burlap or wire netting. Asphalt and net have not proved successful on the Pacific coast,† but a combination of paraffine paint and burlap used there has attracted attention. After removing the bark the surface of the pile is covered with a prepared compound, some of the ingredients of which are paraffine, powdered limestone and kaolin. The pile is then wrapped in jute burlap, and another application of the compound is made. Wooden battens are then nailed along the surface, which receives a final coat of the paint. Piles thus protected have been in use for ten years on the Pacific Coast by the California State Board of Harbor Commissioners, by the Northern Pacific, Great Northern and other railways, and are said to have been successful. The coating protects the piles from the teredo, limnoria and similar animals, but its duration is not known.†

(*g*) Piles are sometimes covered with Portland cement mortar. The bark is first removed and the wood cleared of knots and similar projections. The pile is then driven to its final position. The mortar is applied in several ways. A jacket of ordinary sewer pipes extending from the mud line to high-water mark is sometimes placed around the pile, and the space thus enclosed filled with hydraulic cement. Piles

* *Transactions*, Am. Soc. C. E., Vol. xxxi, p. 235.

† *Engineering News*, February 8th, 1894.

thus protected have been put in position and observed by the California State Harbor Board. The coatings were soon found to have cracked, probably because they were too stiff. An iron shell or mould made in two pieces, bolted together tightly around the pile has sometimes been used. The intervening space is filled with cement, and the mould removed as soon as the cement has become hard. The Louisville and Nashville Railroad treated four thousand piles in this way, at an average cost of $1.25 per foot of length.* The cost of repairs for the first seven years was comparatively small. The concrete became coated with oysters and barnacles and was thus further strengthened. The advantage of such a treatment is that it can be applied after the piles have been driven. Teredos or limnoria may unexpectedly attack the wood, and any specimens which have gained entrance can be killed and others repelled by this method. The cost is not as great as might appear, since the entire length of the pile is not covered.

(*h*) The use of sand has been found to be both effective and low priced. Cylinders of earthenware pipes joined together by a special cement, are lowered over the pile and pushed into the bottom. The space between the cylinder and the pile is filled with sand. Any fracture or leakage is made evident at the top and can at once be made good. This method was suggested by the Louisville and Nashville Railroad, and is considered to be an improvement on their former method of protection by means of cement, while the cost, about 70 cents per foot, is much lower. The method is said to insure greater elasticity and better protection at the bottom. Piles treated in this way on the New Orleans and Mobile Division are apparently as sound as when driven, twenty years ago. In some cases their tops were not covered with pitch when they were sawed off, and the heart wood of a few of these specimens has decayed. The outer sapwood still remains sound.†

(*i*) External protection is sometimes afforded naturally. The surface of the wood may become covered with barnacles, mussels, oysters or similar animals, and is thereby protected from attack. Sea thorns sometimes multiply to such an extent that the entire surface is covered by their disks, which afford a very effective protection.

A Dutch commission, after six consecutive years of investigation, reported that coatings applied to the surface of wood seemed insuffi-

* *Transactions*, Am. Soc. C. E., Vol. xxxi, p. 225.

† *Transactions*, Am. Soc. C. E., Vol. xxxi, p. 221.

cient; that such coatings are likely to be injured by mechanical means; that chemical changes are to be looked for; and that it is difficult to obtain a covering which will continue in close contact with the wood.

The subject of external coatings may be thus summarized : Protection may be afforded as long as the coating remains intact, but this is difficult to accomplish.

Internal Treatment.—Many substances, such as water-glass, the salts of mercury and of iron, have been suggested as substitutes for coal-tar creosote, but none of these can compare with it, and therefore deserve no further notice.

Creosote supplies the best means for repelling the attacks of the teredo, limnoria and other sea animals, and also the termite and other land wood-borers. The subject of creosoting divides itself into three parts: the creosote, the method and the wood.

Creosote is a substance which is contained in the second distillation of coal tar. The first distillation consists of light oils, the second, creosote, and the third, pitch. Tars differ greatly in their chemical constituents, and in their products of distillation. The word cresote, therefore, has not an absolutely exact definition. The substance has no chemical symbol, as it applies to a fluid, the constituents of which constantly differ. It is essential that creosote should be heavier than water, as light creosotes have never been satisfactory, and most of the failures attributed to creosote have really been due to the use of such oils.

Creosote is expected to act in two ways. It introduces antiseptics into the wood; it also fills the pores with thick, gummy insoluble oils and naphthaline. Therefore, a second distillate of coal tar, which contains antiseptics and gummy substances in sufficient quantity and of satisfactory quality, should be selected. It should contain over 40% of naphthaline, and as little pitch as possible. It may contain as much carbolic acid as is likely to be present in this distillate, which will not be over 4 or 5 per cent. No substances likely to accompany the minimum of 40% of naphthaline will be injurious, because many of them may be regarded simply as vehicles. Heavy oil of creosote is heavier than water, and is sufficiently insoluble to remain in the wood for a long time. Creosote weighs from 8 to 9 lbs. to the gallon. The United States cannot meet the demand for dead oil of coal tar, and,

therefore, a large quantity is derived from England. The so-called "London Oil" is very thick and heavy. It is thought to be one of the best grades of creosote for marine work.

The method by which creosote is introduced into the wood is most important, but any method which will insure a thorough impregnation will be satisfactory. The wood is first heated in a vacuum to remove the moisture. The heat is so manipulated as to vaporize the sap and coagulate the albumens of the wood. Heated creosote is then introduced, and the condensation of the vapor in the wood causes a vacuum which, assisted by pressure, draws in the creosote. A gauge outside of the tank indicates the subsidence of the creosote as it passes into the wood. The process is stopped as soon as the specified quantity of creosote, usually from 10 to 16 lbs. per cubic foot of wood, has been forced in.

The selection of the wood which is to receive the creosote is important. Some woods are more porous than others, and one which will permit the free entrance of creosote is better than one which is hard or otherwise durable. It should be of such a nature that it will protect the creosote after impregnation. Creosote has occasionally failed because it has not been used in connection with wood of the proper quality. The Georgia pine and the Loblolly pine are the best for this purpose. Green woods are sometimes preferred to those which have been seasoned, because the condensation of the vaporized sap assists in more thoroughly impregnating the wood.

Many cases of failure are recorded against creosoted wood. Other cases are on record of woods which have resisted at first, but have succumbed after several years of exposure. In all these cases it may be assumed that the creosote was at fault; that the work was not thoroughly done, or that the wood was of a kind which resisted the ordinary treatment. A well-selected wood, thoroughly impregnated with good coal tar creosote, will resist the teredo, the limnoria, and probably all other forms of life for many years.

Substitution.—Substitution can hardly be classified as a method of preservation, but should be mentioned in connection with this subject, because the use of iron in ship-building is constantly increasing. Were this not so, marine wood-borers would require much more attention than they receive at present. Iron piles are used to some extent, and the use of iron work in marine construction may be safely

said to be on the increase. There are many marine works, however, in which iron can hardly be used as a substitute for wood.

The author has received notable assistance from Professor Verrill, of Yale University; Professor Packard, of Brown University; Professor C. O. Siegerfoos, of Johns Hopkins University; the National Museum at Washington, and General John M. Wilson, M. Am. Soc. C. E., Chief of Engineers, U. S. A. The New York Museum of Natural History has permitted the author to photograph some of its specimens. The United States Fish Commissioner has contributed much data, and prepared drawings of the teredo, the limnoria, and the chelura. The New York Aquarium, Colonel William Ludlow, M. Am. Soc. C. E., Francis Collingwood, M. Am. Soc. C. E., T. G. Hoech, M. Am. Soc. C. E., and many others have been of assistance.

DISCUSSION.

Mr. Berg.

WALTER G. BERG, M. Am. Soc. C. E.—Attention should be called to the beneficial effect of emptying sewers and factory refuse near timber structures. It is a well-known fact that, in New York City, piers or harbor timber structures located where the water is heavily impregnated with sewage or factory refuse are not seriously damaged by the teredo. This fact is almost conclusive proof that these animals require for their existence clear, good, salt water.

Mr. Harrod.

B. M. HARROD, Past-President, Am. Soc. C. E.—The engineers of the Louisville and Nashville Railroad have had a very large experience, perhaps the largest in the country, in fighting this mollusk on the Gulf Coast. They have used creosoting extensively, and for this purpose have erected their own works. They have tanks 6 ft. in diameter and 100 ft. long. The sap is extracted by the condensation of the steam, and then the creosote is put in under pressure. Their bridge piles are now standing in good condition, after some 12 years. They have also used cement around the piles, and another method which they have tried seems to the speaker to be very attractive, but he does not know that it has yet been fairly tested. After driving a pile, drain tiles are slipped over it, thus forming a very loosely fitting pipe. The tiles are placed in position by a diver, and then simply filled in with sand. The speaker thinks this is the last experiment they have made and that it is giving good results. It is certainly the cheapest plan yet tried. In connection with this subject, it will be interesting to refer to the paper by R. Montfort, M. Am. Soc. C. E.*

Mr. Manley.

HENRY MANLEY, M. Am. Soc. C. E.—In Boston harbor the teredo, as a rule, is not found. The Cape Cod peninsula seems to be the dividing line; but territory upon the border line may be subject to invasion, and two or three years ago there was a considerable inroad which was wholly unexpected and unprepared for. In this case a dredging company was operating at the mouth of the harbor. In the early spring the company brought some new hard-pine lumber from the South, which had been floated down one of the rivers of Georgia and shipped to Bath, Me. Two large scows, each holding perhaps 500 or 800 cu. yds., were built of this lumber and brought to Boston early in the spring. They were pulled out of the water to be measured by the Government engineers, and then used in the work at the mouth of the harbor. Late in the summer they began to leak unaccountably. On examination they were found to have been thoroughly riddled and bored by the teredos, which were good-sized specimens and of full growth. It was rather a shock to the people having the care of wooden structures in Boston harbor, and they were a little appre-

* *Transactions*, Am. Soc. C. E., Vol. xxxi, p. 221.

hensive; but the following winter destroyed all the teredos, and since that time they have not reappeared. In Boston it has not been thought necessary to use any protection against the teredo, and in an experience of 25 or 30 years the speaker has known of only six or seven isolated cases where the animal has appeared, and then, except as above stated, only as specimens. Mr. Manley.

The limnoria has been found in Boston harbor from time out of mind, and the local engineers find no particular difficulty in guarding against its attacks.

It has long been the practice to specify that in exposed situations the bark upon piles shall be intact, and that the trees used for this purpose shall have been cut at such seasons that the bark will retain its place. So long as the bark remains, the experience has been that it is a perfect protection from the limnoria.

B. L. Crosby, M. Am. Soc. C. E.—Some years ago, on a visit to the East, the speaker took a trip in Boston harbor to what was then called Downer's Landing, and, at low tide, the water being very clear, he noticed that a large number of piles were nearly eaten off; the type of destruction being that of limnoria. That is, the wood was gone, so that the points of many of the piles near the ground line looked as though they had been sharpened like a lead pencil. A new wharf was then being built and was only finished in time. Mr. Crosby.

Robert Moore, M. Am. Soc. C. E.—A new process for preserving piles consists of the application of a cement of a somewhat new type called lithocite. It is said to harden rapidly into a very hard mineral substance. The method of application is to wrap the pile in gunny-sack, or similar material, and then saturate it thoroughly with this cement in liquid form. This, of course, can be done by wrapping with one or more thicknesses of the gunnycloth, and when it is applied in this way it is said to form a hard and perfect protection against the entrance of the teredo or any other marine pest. The method of application is simple, and is said to cost about half as much as creosoting. The experience of two or three years, perhaps more, is said to show that it affords a perfect protection. If what is claimed for it is verified by experience, it will certainly be an important addition to the resources of the engineer in fighting marine pests. The speaker believes that it has been used along the Gulf Coast at several points, and that it has been used by the Louisville and Nashville Railroad, and upon some of the government works on the Florida Coast. Mr. Moore.

CORRESPONDENCE.

Mr. Collingwood.

FRANCIS COLLINGWOOD, M. Am. Soc. C. E.—The paper is, altogether, the best exposition of the subject that the writer has seen, and is so complete that little room is left for discussion.

As to the depths at which these animals work, the writer wishes to mention the following instance. The site of the New York tower of the East River Bridge (at Pier 29, East River) was dredged to 31 ft. below high water. It was found that the dredge missed the ends of some piles that had been eaten off at about the mud line, say 30 ft. to 32 ft., and these were pulled up by chain attached by divers. Whether the worm was the teredo or not the writer cannot now remember.

The alarm about the caissons, mentioned by the author as existing at that time, arose from the fear that these animals might continue their work after the caissons were sunk in the bottom, even below the earth. After consulting many authorities, the writer reached the same conclusions as the author.

The paper is complete, and leaves nothing to be desired. Of course, the subject of remedies or prevention of the ravages of the worms is an extensive one, but it has been pretty thoroughly threaded over.

The writer's advice on this subject would be that patent nostrums should be avoided.

Mr. Le Conte.

L. J. LE CONTE, M. Am. Soc. C. E.—The Pacific Coast teredo is a very active mollusk, and when fully developed is $\frac{3}{4}$ of an inch in diameter and 36 ins. long. It is especially vigorous at and near the entrances to harbors where the flood tide waters come in fresh from the sea, and more particularly at those sites where the tidal currents are strongest and the food supply naturally plentiful. In such places the teredo will destroy a 14-in. pile completely in three months.

The teredo, as found on the Pacific Coast, is quite sensitive to the influence of fresh water encroachments, and as a result at different portions of the bay of San Francisco the difference in the activity of the teredo is very great—the life of a pile varying from three months to seven years. The worst experience with the teredo on the Pacific Coast has been the increase in its range of activity during the past ten years—the teredo now attacking greedily many kinds of materials which formerly were avoided. This apparent change in its habits is probably due to a variety imported by vessels plying to and from Mexican ports.

Some ten years ago the specifications of the Harbor Commission Engineer demanded that all piles furnished should have a perfect coating of natural bark; the trees to be felled in the winter months when the bark is more adherent. Now the teredo pays little or no

attention to the bark. The writer has seen several samples which were completely riddled with teredo holes. Mr. Le Conte.

The comparative freedom of the endogenous woods—palms and palmettos—from the ravages of the teredo seems to be due more to the very spongy character of the wood than to any other quality. This porosity readily admits the approach of the enemies of the young teredo before he is fully able to make a tube to protect himself. The natural enemies of the teredo should be studied and cultivated.

The *limnoria lignorum* mentioned by the author is a terrible pest on the Pacific Coast, and from a broad point of view is more destructive because of its much wider range of activity. The chelura has not been definitely recognized on the Pacific Coast by competent authority, although it may exist.

As to methods of protection, the outside coating, such as copper, zinc or the Paraffin Paint Company's coating are good preventives as far as they go; but by these processes the life of the pile is transferred to the natural life of its unprotected head, above the coatings, which generally decays so as to be unfit for service in about seven to eight years, sometimes longer. Dutch flat-headed nails have been used in San Francisco Bay by the United States Engineers, with marked success, against the teredo, but are of indifferent value as against the limnoria.

Creosoting properly done, with an ample amount of dead oil of good quality, is the best process yet devised as a protection against sea animals of all kinds, since it insures also against ordinary decay. The history of protective coatings for the past fifty years is, unfortunately, full of many inexplicable failures. Hence the slow advances made in practice. A study of these failures is quite interesting. A large percentage of them is charged to poor oil, whereas examination shows that such a charge is unfounded.

A large majority of these failures can be traced to the fact that it is very frequently impossible to impregnate a wooden pile with much uniformity in depth of penetration, some portions of the wood being close grained and hard, while other portions are much softer and more porous. Hence, during the time that the dead oil is being forced in under pressure it naturally penetrates through those channels which offer the least resistance to progress, and, consequently, most of the oil goes into the softer portions of the wood and avoids the denser portions.

It is evident that the quantity gauge, which keeps a record of the number of gallons of oil introduced per cubic foot, for the entire pile, can furnish no guarantee whatever as to whether the work done is first class or very inferior.

The writer has seen a creosoted pile, passed by inspectors as a good job, taken to a saw mill and cut up into short lengths, and the cuts

Mr. LeConte. examined. The inequality in depth of penetration was remarkable being in some places as much as 3 to 4 ins., and in the denser portions not over $\frac{1}{20}$ of an inch.

Along the west coast of Mexico the sea animals are unusually active, and piers are generally built on a foundation composed of wrought-iron piles 6 to 9 ins. in diameter. Iron and steel are being produced so cheaply that it begins to look as if this is the most practical solution of the problem.